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a-SiGe:H Deposited by Hot-Wire CVD Using a Tantalum Filament Operated at Low Temperature

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A.H. Mahan, Y. Xu, and L.M. Gedvilas

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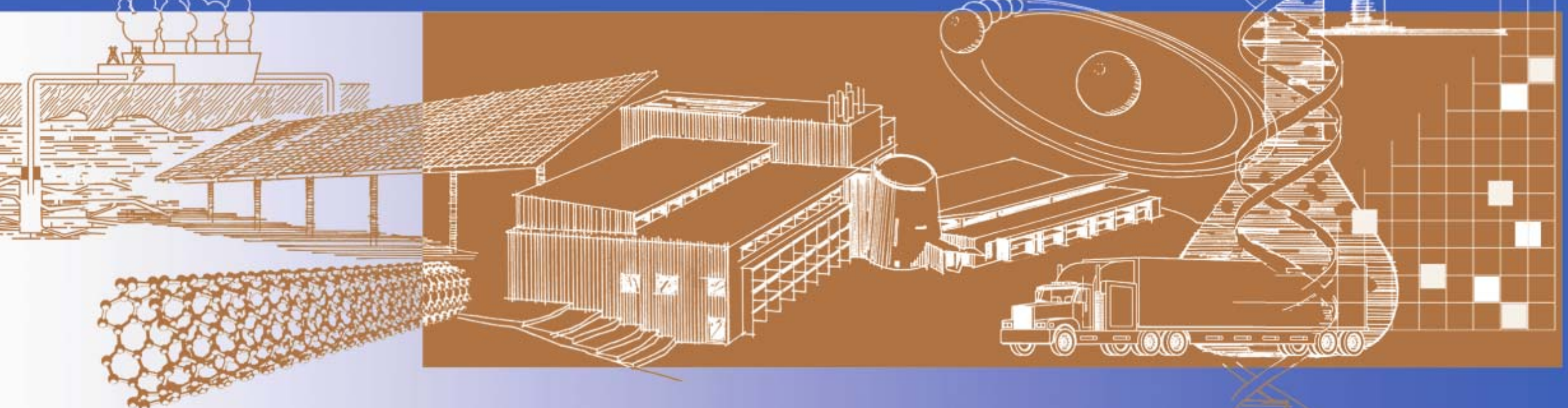

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A.H. Mahan, Y. Xu, and L.M. Gedvilas
National Renewable Energy Laboratory (NREL)
1617 Cole Blvd., Golden, CO 80401 (harv_mahan@nrel.gov)

ABSTRACT

We report the deposition of optimum-quality a-SiGe:H and a-Si:H by the hot-wire chemical vapor deposition (HWCVD) technique using a tantalum filament operating at a low temperature. We gauge the material quality of the a-SiGe:H films by comparing infrared, small-angle x-ray scattering, photocapacitance, and conductivity results to those presented elsewhere.

1. Introduction

The incorporation of high-Ge-content a-SiGe:H into a low-bandgap solar cell commonly involves the use of bandgap (Ge) profiling, where the material with the lowest bandgap, or the highest Ge content, is placed near the middle of the i-layer to avoid an abrupt bandgap transition at the n/i and p/i interfaces [1,2]. Since in this approach the material must be profiled over a wide range of Ge content, all i-layer alloy compositions must be of device quality and must be deposited using similar process conditions. This work reports on deposition of optimum-quality a-SiGe:H by the HWCVD technique using a tantalum (Ta) filament operating at low temperatures [3]. We gauge the material quality by comparing infrared, small-angle x-ray scattering (SAXS), and photocapacitance results to those presented elsewhere, and conclude that the structural heterogeneity of the HWCVD a-SiGe:H films can be significantly reduced compared to those deposited by plasma-enhanced chemical vapor deposition (PECVD) by using low filament temperatures. We show that this improved structural homogeneity translates into improved electronic properties, as measured by the σ_l/σ_d conductivity ratio.

2. Experimental

The a-SiGe:H films were grown by HWCVD using a 0.5-mm-diameter Ta filament located 5 cm from the substrate holder, in a tube reactor described elsewhere [4]. Table 1 gives representative deposition parameters for an a-SiGe:H film containing ~65 at.% Ge using a filament temperature of 1750°C and a T_{sub} of 200°C. The Ge film content was varied by changing the GeH_4/SiH_4 gas flow ratio. Each film was deposited simultaneously on 1737F Corning glass and c-Si wafers, with evaporated coplanar (width to length = 0.05) Cr contacts on the films on the 1737F substrates enabling conductivity measurements. Optical measurements were performed on these films using an n&k 1280 Analyzer to determine the Tauc's bandgap, whereas Fourier transform infrared absorption spectra were obtained from transmission measurements for the films deposited on the c-Si wafers using a Nicolet 510 system operating between 400 and 4000 cm^{-1}. Secondary ion mass spectrometry measurements of the Ge film content enabled the preferential attachment ratio (PA) to be calculated. In a separate series of depositions, 1.5–2.0-µm-thick films covering a wide range of Ge contents were deposited on high-purity Al foil for the SAXS measurements, and on SS/n^+ layers for the photocapacitance measurements.

Table 1. Representative Deposition Parameters for an a-SiGe:H Film Containing ~65 at.% Ge.

SiH_4 (sccm)	GeH_4 (sccm)	H_2 (sccm)	P_{ch} (mT)	R_d (Å/s)	E_g (eV)	σ_l/σ_d
16	9	25	12.5	2.5	1.23	140

3. Results and Discussion

Previous work has reported the infrared (IR) stretch mode bonding configurations for HWCVD films deposited for Ge film contents ranging between 0 and 100% [5]. Of interest are the virtual lack of SiH_2 and/or $(SiH_2)_n$ bonding appearing in the 'shifted' mode at 2090 cm^{-1}, and the relative amount of H bonded to Ge atoms versus Si atoms. In Fig. 1 we show the IR $SiH_2/(SiH+SiH_2)$ intensity ratio (R) for Ge film contents ranging from 15 to 80 at.%. This ratio for the HWCVD films is at most 0.1 and becomes difficult to detect for Ge film contents exceeding 50%, whereas that for the PECVD films [6,7] is a factor of 2–3 higher and, for one of the studies, shows an opposite trend for higher Ge film contents [7].

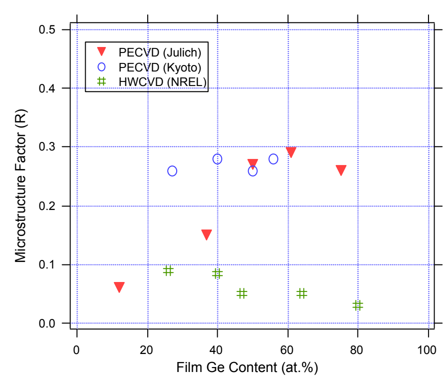

Fig. 1. R versus film Ge content.

Figure 2 presents SAXS data for low T_{fil} for film Ge contents ranging from 0 to 80 at.%. Whereas prior trends in SAXS densities with increasing film Ge content show a significant increase in SAXS signal for very low Ge incorporations [8], the present curve remains lower than the 'standard' curve over the whole composition region. The only films with lower SAXS values are those deposited using high-bias microwave conditions, and these have high defect densities due to the high energy bombardment conditions. We further suggest that these low SAXS densities for the present HWCVD films, achieved with minimal bombardment energies, have a beneficial effect on the films' electronic performance.

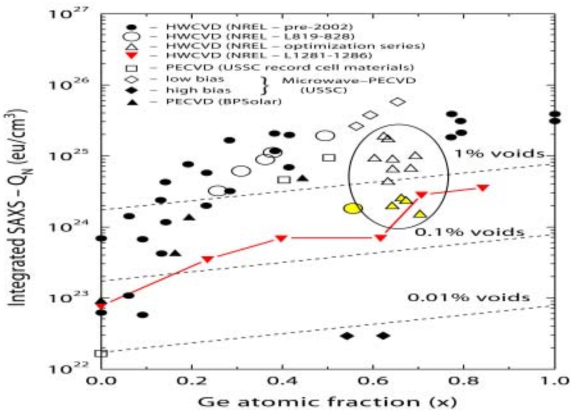

Fig. 2. Integrated SAXS intensity versus film Ge content.

The other factor contributing to the improved structure of the present HWCVD a-SiGe:H films is the increase in the amount of GeH bonding. Assuming that the proportionality constants for the SiH and GeH stretch modes are similar, we determine the amount of SiH and GeH bonding by normalizing these stretch mode areas to the films' H content. These results, shown in Fig. 3 along with representative PECVD data [6], translate into lower preferential attachment ratios for the HWCVD films over the whole range of film Ge contents [5].

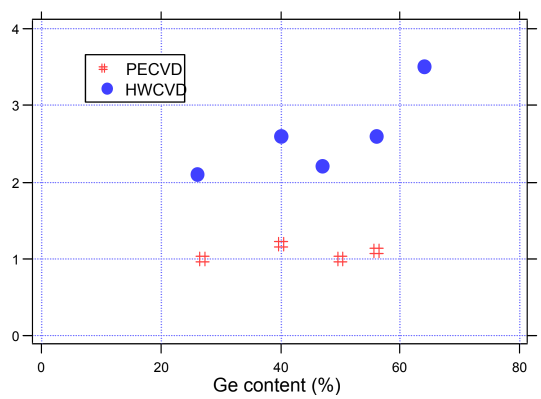

Fig. 3. Ge-H bonding (at.%) versus film Ge content.

Because of these improvements in film heterogeneity, we have submitted a series of a-SiGe:H films for photocapacitance measurements of the film bandtails and defect densities. Preliminary results for the first film, containing ~29% Ge, have been obtained. In this film, the Urbach edge value of 42 mV is quite narrow and compares favorably with the narrowest Urbach edges measured for any a-SiGe:H film [9]. Measurements are in progress to determine the film defect density for this film and to extend the results to other film Ge contents.

4. Conclusions

We have reported the deposition of optimum-quality a-SiGe:H by the HWCVD technique using a tantalum filament operating at a low temperature. We have gauged the material quality of the a-SiGe:H films by comparing infrared, SAXS, photocapacitance, and conductivity results to those presented elsewhere, and have concluded that the present films exhibit a significantly improved structural heterogeneity compared to films deposited by the PECVD technique.

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The authors thank D.L. Williamson and J.D. Cohen for SAXS and photocapacitance measurements on these films. This work was supported by DOE Contract No. DE-AC36-99GO10337.

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